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DEPOSITION OF CERAMIC COATING ON THE SURFACE OF A POROUS MATRIX OF INFRARED GAS BURNER

O.V. Kolisnichenko, Yu.M. Tyurin, M.A. Polieshchuk

E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine

ABSTRACT

A technology is proposed for deposition of a ceramic coating on the surface of Fechral porous matrix to improve the performance of infrared burners. Multichannel detonation device allows forming coatings on the working surface without any significant changes of its surface permeability. Presence of Al_2O_3 ceramic coating on the pore walls changes the burning mode. The flame front moves into the matrix to a small depth behind the coating that leads to reduction of harmful emissions at fuel mixture combustion: carbon monoxide by 50 % maximum, nitrogen oxide by 10–15 %. The effectiveness of matrix radiation increases up to two times in the spectral infrared range of wave length from 5 up to 14 μm.

KEYWORDS: porous metal matrices, infrared radiation, detonation spraying, ceramic coating, harmful emissions, radiation intensity

INTRODUCTION

Application of porous materials in everyday life and in engineering is due to their unique properties. For instance, porous metal matrices have a small weight, combined with a high strength, which allows using them in light structural elements, acoustic insulation, energy absorption system and vibroextinguishers [1]. They also have a large area of inner surface and high heat conductivity, and, thus, are ideally suitable for application as heat exchangers, heat sinks, boilers, burners and reactors for synthesis gas production. High penetrability of porous materials for the gas flow and their huge surface area ensure the high speed of heat transfer at low pressure gradients. At present, manufacture and application of infrared (IR) gas burners is developing intensively due to their high effectiveness. They are used in many technological and household appliances. In them a considerable part of energy from the heater is transferred to the heated object due to radiation. The operation of IR burner is based on complete oxidation of earlier prepared gas-air mixture on a permeable matrix, which radiates thermal energy in IR range at heating. Burning of gas mixtures on the porous matrix surface takes place at a lower temperature, compared to gas flaring due to intensive heat removal from the zone of chemical transformation into the matrix body. The main characteristics of this type of burners are radiation flow density and, which is particularly important for household appliances, low quantity of toxic gases in the combustion products. In order to increase the effectiveness of IR burners, it is very important to ensure complete combustion of the gas mixture and respective lowering of carbon oxide due to longer time of combustion products staying in the high-temperature zone. It can be achieved by application of radiation screens in the form of net or perforated plates over the matrix surface, as well as by the method of gas combustion in the deep cavity of the matrix, or by transition from the topography of a flat to a bulk matrix [2]. Heat-conducting elements are also used in the form of plates, lying on the surface, as well as those penetrating into the matrix body [3]. Such a design of IR burner allows increasing the gas mixture preheating during its movement through the permeable matrix and matrix surface temperature. Heat-conducting plates (recuperators) separate from the combustion products and transfer to the surface and into the matrix body an additional heat flow due to heat conductivity, and also ensure additional heating by radiation from the surfaces of heat-conducting elements, located in the area of the combustion products. Coating of the matrix surface by material with different thermophysical properties also changes the energy and ecological characteristics of the burner device. Moreover, it can be used as an additional measure as to the structural methods of increasing the effectiveness of IR burners. The objective of this work was optimization of deposition technology and studying the structure and properties of a dense ceramic layer on the surface of a porous matrix of a gas burner, as well as testing gas burners with a ceramic coating, determination of the effectiveness of reducing the harmful additive emission and increasing the efficiency.

EQUIPMENT, MATERIALS AND PROCEDURES OF INVESTIGATION

The object of study was a porous matrix of 250×250×10 mm size from Fechral alloy with bulk

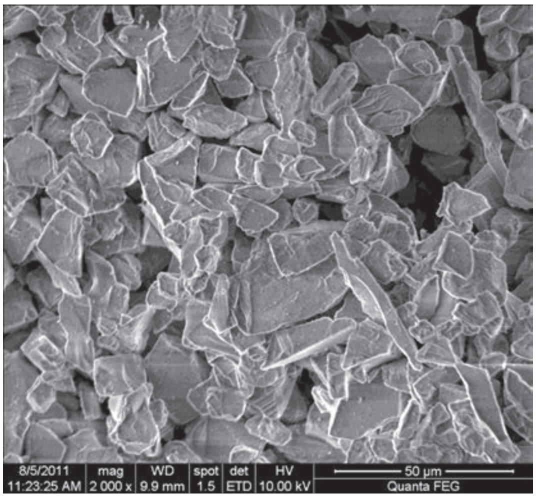

Figure 1. Appearance of AMPERIT® 740.0 Al_2O_3 powder in REM Quanta600 FEG, 10 kV accelerating voltage

porosity $\eta_v \approx 0.9$, surface permeability $\eta = 0.4$ and average pore diameter of 0.5–0.8 mm. Aluminium oxide was selected as the coating material with maximum application temperature of 1650 °C, that is higher than the porous matrix heating temperature during operation. The coating on the working surface and in the matrix pores was formed from AMPERIT® 740.0 Al_2O_3 powder (Figure 1) of H.C. Starck Company (5.6–22.5 μm fraction) by detonation spraying method. Used for this purpose was a multichamber detonation sprayer (MCDS) developed at PWI [4]. Investigations of optimization of the ceramic coating deposition modes were conducted in automated equipment (Figure 2), consisting of MCDS, manipulator, standard low-pressure gas panel (up to 3 atm) for feeding oxygen, propane and air, scraper powder feeder of SX-03-2 type of Guangzhou Sanxin Metal S&T Co., Ltd. (China), and automated system of technological process control.

One of the key parameters, determining the physicochemical processes of material interaction and the actual possibility of high-quality coating formation, is the speed and temperature of the powder particles at the moment of collision with the substrate. With this purpose, the mode of compressed detonation combustion of the gas mixture in specially profiled chambers is realized. The accumulated combustion energy from two chambers in the cylindrical barrel ensures formation of a high-speed jet of detonation products, which accelerates and heats the sprayed powder. Here, the speed of powder, for instance Al_2O_3, reaches 1000 ± 200 m/s [5]. Coating deposition by thermal methods on thin-walled parts is a complicated task, because of the strong thermal impact on the surface. It may lead to intensive overheating, sprayed surfaces oxidation and, consequently, deterioration of adhesion, and usually also destruction of the product proper. The process cyclicity is one of the advantages of the detonation method that allows lowering the spraying zone temperature. Air blowing (6 m^3/h) through the entire back surface of the porous matrix was realized for additional cooling of the product. Gas and powder feeding was continuous. The detonation sequence frequency was 16 Hz, powder consumption was 0.6 kg/h, speed of MCDS longitudinal movement relative to the product was 50 mm/s. The composition and flow rate of the combustible gas mixture components are given in Table 1.

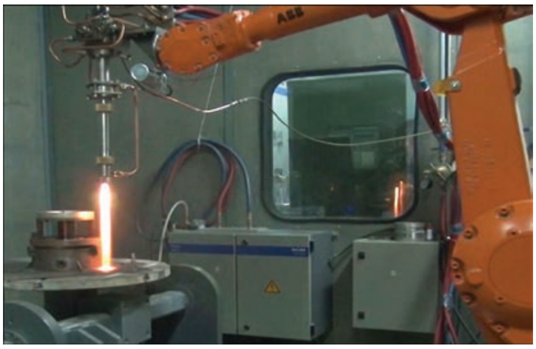

Figure 2. Device for coating deposition using MCDS

Table 1. Composition and flow rate of combustible gas mixture components

Combustible mixture components	Gas flow rate, m^3/h
1st chamber	
O_2	3.9
Air	0.1
C_3H_8	0.71
2nd chamber	
O_2	3.6
Air	0.11
C_3H_8	0.66

Investigations of the microstructure and elemental composition of the layer of Al_2O_3 ceramics were conducted using scanning electron-ion microscopes Quanta 200 3D and Quanta 600 (REM), fitted with energy-dispersive X-ray spectrometer of PEGASUS system of EDAX Company. Porosity was determined by metallographic method with elements of qualitative and quantitative analyses of pore geometry with application of optical inverted microscope Olympus GX51. Investigations of the ceramic layer and substrate hardness were conducted using automated system DM-8 of microhardness analysis by microVickers method at 25 g loading on the indenter.

RESULTS AND THEIR DISCUSSION

Thermal spraying methods are effectively applied to create an impermeable surface layer on porous ma-

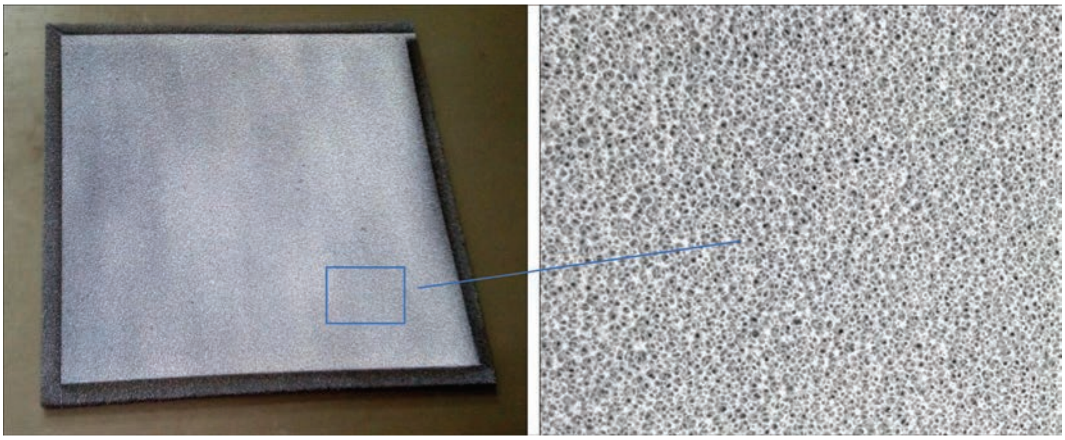

Figure 3. Porous matrix with a coating

trices of heat exchangers [6, 7]. Unlike heat exchangers, the coatings on IR burners must preserve open porosity. As was noted above, one more problems, which comes up during thermal spraying of coatings on thin-walled and laced products is the large heat flow, leading to product overheating. A series of experiments were conducted on determination of the influence of spraying distance on the process of ceramic coating deposition on porous matrices. The distance was varied in the range of 100–200 mm at other technological parameters remaining constant. At 200 mm distance, the powder speed reaches the maximum value at a slight reduction of the maximum temperature of powder particle heating [8]. At large distances, the combustion product temperature and speed also decrease, leading to reduction of gas-dynamic and thermal impact on the thin walls of matrix pores. As a result of the conducted experiments, it was established that at the set technological parameters of spraying with MCDS and additional air cooling the minimal distance from the nozzle edge to the surface, at which no matrix destruction or overheating occurs, is 180 mm. Deposition of the ceramic coating on porous matrices was performed with sixfold overlapping of spraying tracks. Appearance of the coated product is shown in Figure 3.

At spraying the coating follows the surface relief and does not lower the surface permeability of the matrix (Figure 4, *a*). The thickness of the coating on the matrix surface is equal to 100 μm on average. On the matrix transverse fracture one can see that due to reflection from the membranes the coating forms not only on the surface, but also on the walls of the matrix subsurface pores and reaches a thicknesses of 20 μm.

The ceramic layer microhardness is equal to 1320 ± 25 $HV_{0.025}$, porosity is below 2 %. Values of microhardness measurements cross the layer have little discrepancy that is indicative of the homogeneity of the layer of deformed powder particles which closely adhere to each other and also of its phase and structural homogeneity. The coating adheres to the matrix without defects or delaminations. Considering the high-temperature conditions (higher than 1400–1450 °C) of formation of Al_2O_3 coating on the thin walls of the pores, we can state that its phase composition is represented predominantly by α-Al_2O_3 modification [9]. Elemental composition of the matrix and coating material determined by the method of anal-

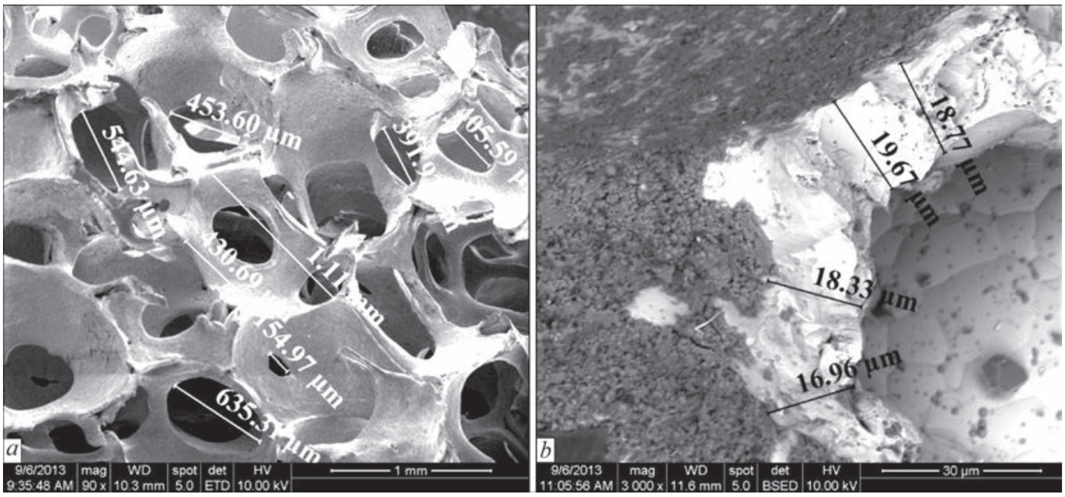

Figure 4. Matrix after spraying: *a* — appearance of surface pores; *b* — coatings on pore walls at 2 mm depth from the matrix surface

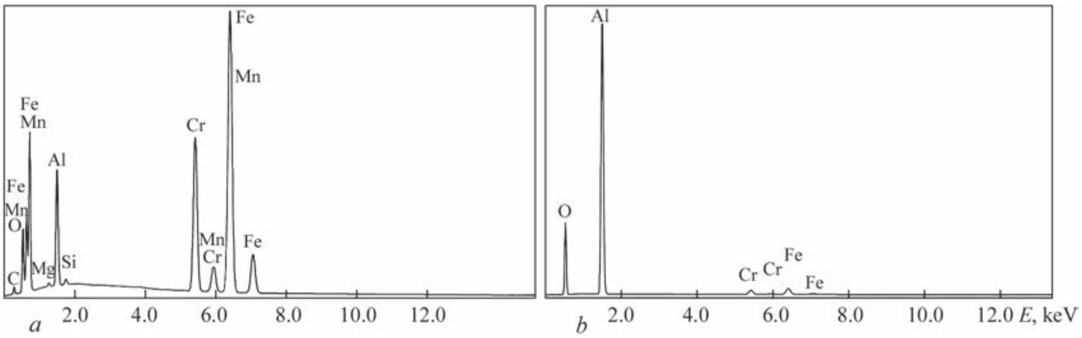

Figure 5. Spectrum of characteristic X-ray radiation of the material of matrix (*a*) and coating (*b*)

Table 2. Elemental composition of a porous matrix and coating, wt.%

Element	Porous matrix	Coating
O	3.57	33.53
Al	9.25	59.27
Cr	20.69	2.43
Fe	64.11	4.78
Mn	1.28	–
Mg	0.34	–
C	0.37	–
Si	0.39	–

ysis of the spectra of characteristic X-ray radiation (Figure 5) is given in Table 2. Heat conductivity of Al_2O_3 coating in the working temperature range of IR burner (up to 1300 °C) is equal to 6 W/(m·K) on average, and that of Fechral material of the porous matrix is 16 W/(m·K). Difference in heat conductivity as shown below, influences the process of combustible mixture burning proper.

Testing porous matrices with and without coating was conducted in work [10]. Combustion of mixtures of natural gas with air on the surface of porous matrices with a ceramic coating was tested at variation of specific thermal load. Radiation temperature of the surface of uncoated and coated areas and the respective temperatures on the matrix reverse side were measured. Visible glow of the surface of initial matrix area without coating was brighter than that of an area with a ceramic coating. However, the area surface temperatures measured by a pyrometer, turned out to be exactly the opposite. The temperature of a surface with a ceramic coating was approximately 200 K higher. Such a significant temperature difference can be explained by that in the coated matrix area the flame front penetrates deeper into the matrix pores as a result of reduction of the coefficient of surface heat conductivity, and the area of contact of the reaction zone with the pore surface becomes larger. The temperature of the matrix subsurface layer rises. The radiation pyrometer records increased temperature, as the ceramic coating is transparent in a broad spectrum of IF radiation. In matrices with a ceramic coating, the flame zone moves into the pores below the matrix surface, and redistribution of energy evolving at gas mixture combustion takes place. The energy radiated by the surface becomes greater. The combustion product temperature and energy carried out by the combustion products, decrease.

Energy redistribution results in increase of the coefficient of radiation efficiency of the burner at ceramic coating deposition. The effectiveness of radiation of a matrix with a ceramic coating is up to 2 times higher in the spectral range of wave lengths from 5 to 14 μm. The amount of harmful emissions in the combustion products is also reduced (carbon monoxide — 2 times, nitrogen oxide — by 10–15 %).

At mixture depletion (increase of excess air coefficient), the temperatures of the surface layer and reverse side of both the matrix areas decrease monotonically that is related to reduction of the mixture calorie content. Here also the temperatures of a matrix with the ceramic coating are higher in the entire range of excess air parameter variation. Thus, unlike the surface burning on a porous metal matrix, a change of burning mode occurs at deposition of a thin ceramics layer on its surface. The flame front penetrates into the matrix to a small depth beyond the coating film, and its temperature grows significantly. Distribution of energy generated due to the combustible mixture burning, takes place. As the temperature of the matrix surface layer becomes higher, it results in enhancement of the radiation flow, and simultaneous lowering of the temperature of the combustion products that should lead to lowering of the rate of formation of nitrogen oxides and carbon monoxide.

In the matrix area with a ceramic coating at a high thermal load, nitrogen oxide formation is reduced 2 times. At the mixture dilution by air the content of carbon monoxide and nitrogen oxides drops monotonically. Close to the boundary of surface combustion at power density of 33 W/cm^2, carbon monoxide concentration is just ~10 ppm, and nitrogen oxide concentration is close to 3 ppm. Experiments showed that owing to ceramic coating, the thermal strength of the matrix increased, the concentration limits of surface combustion became wider that allows extending the service life of porous metal matrices and reducing the material content of burner devices.

CONCLUSIONS

1. Detonation method with application of MCDS was used for deposition of an aluminium oxide coating on the surface of a porous matrix with preservation of its surface permeability.

2. Presence of a ceramic coating with a smaller coefficient of heat conductivity than that of the matrix material, changes the modes of burning of the combustible gas mixture. The flame front penetrates into the matrix to a small depth beyond the coating layer, improving the performance of IR burners.

3. Application of a porous matrix with a ceramic coating in IR burners allows increasing the burner efficiency and reducing the amount of harmful emissions in the combustion products (carbon monoxide — 2 times, nitrogen oxide — by 10–15 %), and significantly extending the burner operating life.

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ORCID

O.V. Kolisnichenko: 0000-0003-4507-9050,
Yu.M. Tyurin: 0000-0002-7901-7395,
M.A. Polieshchuk: 0000-0002-5992-4641

CONFLICT OF INTEREST

The Authors declare no conflict of interest

CORRESPONDING AUTHOR

M.A. Polieshchuk
E.O. Paton Electric Welding Institute of the NASU
11 Kazymyr Malevych Str., 03150, Kyiv, Ukraine.
E-mail: dep_6@paton.kiev.ua

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